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REVIEW OF FLIGHT TRAINING TECHNOLOGY

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Human Performance Enhancement

Research Problem Review-76-3

REVIEW OF FLIGHT TRAINING TECHNOLOGY

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Research Problem Reviews are special reports to military management. They are usually prepared to meet requests for research results bearing on specific management problems. A limited distribution is made--primarily to the operating agencies directly involved.

FOREWORD

Within the Army Research Institute for the Behavioral and Social Sciences (ARI), the Human Adaptability and Organizational Effectiveness Technical Area performs research to improve the performance of groups in a variety of military systems and operational units. Programs in the Technical Area include research in human sensory, motor, perceptual, and cognitive factors, and effects of stress and degradation of sensory cues--in this case, the problems of helicopter crews flying at nap-of-the-earth (NOE) altitude (i.e., below treetop level) to evade detection.

This report reviews the technology of simulated flight training and is part of a project to identify specific areas in which NOE training for aircrews can be improved. The conclusions of the study are being published as an ARI Research Report, and the detailed task analyses and training objectives from which the conclusions were drawn are tabulated in ARI Research Memorandum 76-2. The entire project was done in close cooperation with the Army Aviation School at Fort Rucker, Alabama; the contributions of military personnel there and elsewhere are gratefully acknowledged. Further studies of human resources in aviation, including flight training selection, simulation, and NOE training, are being done by the ARI Field Unit at Fort Rucker.

ARI research in aircrew performance is conducted as an in-house effort augmented by contracts with organizations selected as having unique capabilities for research in flight technology. This project was conducted jointly by personnel from ARI and Anacapa Sciences, Inc. of Santa Barbara, California, who also requested Dr. Roscoe to contribute his experience in flight training; Dr. David Meister of ARI directed the project, and Mr. Charles A. Gainer led the research for Anacapa. The entire project was conducted under Army RDTE Project 2Q162107A745, FY 73 Work Program, and 2Q764715A757, FY 1974 Work Program, in preparation for responding to special requirements of the Assistant Chief of Staff for Force Development and the U.S. Army Training and Doctrine Command.

J. E. UHLANER
Technical Director

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REVIEW OF FLIGHT TRAINING TECHNOLOGY

BRIEF

Requirement:

~~To review~~ the state of the art of aircrew training technology, particularly in simulation, as part of a program to identify areas in which nap-of-the-earth (NOE) aircrew training might be most readily improved.

Review Summary

Ground-based devices that simulate flight are both effective and cost-effective for initial flight training; with time, as a student's skill increases, the simulator becomes decreasingly cost-effective compared with actual flight. The more complex and costly the simulator, the sooner it will cease to be cost-effective but the more realistic its simulation is likely to be. Optimum fidelity must be determined for each training objective; although more realistic simulation does not necessarily produce more effective transfer of training generally, exact fidelity is vital in teaching procedural skills.

Present flight simulators are much less useful in NOE training than in general helicopter pilot training because they cannot properly reproduce the visual field outside the cockpit. They might be used to train pilots in procedures to cope with NOE-altitude emergencies; however, a combination of cinematic simulation and air training appears to be the most promising cost-effective method of developing NOE visual perception skills.

Of other innovations in pilot training, computer-assisted instruction can be used for any lecture-type training; measurement of residual attention could be useful in assessing NOE pilot performance. Automatically adaptive training methods are not presently suitable for NOE. Automatic performance measurement could be very useful to provide objective assessments once the pivotal measures that correlate highly with total performance are identified.

Utilization:

The conclusions of this review of existing technology were used in conjunction with training objectives derived from task analyses to suggest improvements for NOE aircrew training. These suggestions, validated by the results of ARI's field research program, were used as the basis for the experimental MAP Interpretation Terrain Analysis Course (MITAC) now being evaluated at the Army Aviation School, Fort Rucker, Alabama.

REVIEW OF FLIGHT TRAINING TECHNOLOGY

CONTENTS

SIMULATED FLIGHT TRAINING

BACKGROUND

Simulated flight training has come a long way from the clipped-wing-Penguin-type trainer of World War I.[1] During World War II, the Link C-3 and AN-T-18 "blue boxes" and their close descendents--the School Link, 1-CA-1 and 1-CA-2 (Navy, SNJ; Air Force, P-1), and the GAT-1--were and are effective training devices. All carefully controlled experiments have supported the use of ground-based trainers during initial flight training.[2]

Modern flight simulators, featuring complex visual and motion systems, have demonstrated effective transfer of training, although they have not been submitted to a rigorous experimental evaluation. The dramatic 89% reduction in helicopter flight hours which was claimed by substitute training in the Army's 2-B-24 Synthetic Flight Training System (SFTS) simulator (Caro, 1972; 1973) lends support to the conclusion that such complex devices are effective for both the training and testing of pilots.

COST EFFECTIVENESS

The key requirement in the design and use of simulated flight trainers is cost effectiveness. That is, the cost of the feature, and of the simulator operating time associated with its use, must be no greater than the cost of the flight time required to achieve the same training in the actual aircraft. To make this determination, the use of the simulator should take into account its incremental cost effectiveness (Micheli, 1972; Roscoe, Denney, and Johnson, 1971; Povenmire and Roscoe, 1973).

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[1] The Penguin system involved a clipped-wing Bleriot Aircraft and was used for preflight training for single-seat aircraft.

[2] The early transfer of training studies at the University of Illinois by Williams and Flexman (1949a; 1949b; 1949c) were followed by those of Flexman, Matheny, and Brown (1950); Flexman, Roscoe, Williams, and Williges (completed in 1950 but unpublished until 1972); and Payne et al. (1954). Two studies done at the USAF Basic Pilot Training Research Laboratory using the Link P-1 were reported by Flexman, Townsend, and Ornstein (1954) and by Ornstein, Nichols, and Flexman (1954). Recently, Povenmire and Roscoe (1971; 1973) have resumed transfer research at the University of Illinois with their measurement of the cumulative and incremental transfer effectiveness of the Link GAT-1.

Incremental cost effectiveness refers to a principle of diminishing returns; training in a simulator on any flight curriculum yields a diminishing transfer to actual flight training. At some point, simulator training becomes cost ineffective. Of course, further use of the same simulator for other portions of the curriculum may continue to be cost effective. And at times it may be good training strategy to use a simulator beyond its cost-effective point, for example in bad weather.

Cost effectiveness of a synthetic training device depends both on the cost of the device and on its transfer effectiveness. For a new training device, relatively simple features may become the rational cost-effective choice when they yield only slightly less transfer than more complex and costly alternatives. Stated another way, training may be done more profitably in a cheap simulator with a high transfer effectiveness ratio than in an expensive simulator with an even higher one.

The cost of a synthetic flight trainer includes not only the purchase price, housing and maintenance expenses, but also the energy required to operate the device. Although no existing flight simulator expends energy at the rate of a high-performance military aircraft, the original maintenance costs of some simulators are comparable to the counterpart airplanes. Furthermore, the complex motion and visual systems of the most advanced contact flight simulators and their supporting computers require several times as much operating power as their counterpart undergraduate flight trainers. Thus, to be energy effective, each hour in the simulator would have to save aircraft flight hours in the ratio of the energy used by each machine.

Because the transfer effectiveness of any training device decreases as training time increases, a simulator with an initial positive energy effectiveness will become negatively effective for each student after some period of training on any individual unit of instruction. That point might easily occur before the student has reached the desired performance criterion for that unit.

Predicting the characteristics of a helicopter simulator for NOE operations that will yield high transfer effectiveness ratios relative to cost requires an analysis of training objectives and a realistic assessment of the current state of the simulation art. Discussions of these subjects are provided by Air Force Human Resources Laboratory Technical Note TR 73-01 (Bell, 1974); Baum, Smith, and Goebel (1973); Caro (1973); McGrath and Harris (1971); Puig (1970); Smode, Hall, and Meyer (1966); Valverde (1968, 1973); Willeges, Roscoe, and Williges (1973); and Watson, Cooles, and Hotz (1971).

STATE OF THE SIMULATION ART

Although flight simulator characteristics for NOE training cannot be specified without considering the state of the simulation art, the state of the art should not determine by default the specified simulator characteristics. Each simulator manufacturer recommends to users the most advanced equipment features he can readily produce. Often a manufacturer's recommendations, and his statements as to what he can and cannot deliver within a particular schedule, determine the characteristics to specify. Immediate training objectives rarely determine these specifications. The temptation is to buy overly complex and costly simulators.

Willeges, et al. (1973) illustrate the problem as it manifests itself in the specification of motion system characteristics:

> In view of the large sums invested in the design, development, and production of complex simulator motion systems, it is difficult to understand why there has been no objective controlled experiment to assess their transfer effectiveness. An experiment by Matheny, Dougherty, and Willis (1963) showed that relatively faithful cockpit motion improves pilot performance in the simulator, presumably by providing alerting cues, and recent experiments at Ames Research Center (Guercio and Wall, 1972) and at the Aviation Research Laboratory of the University of Illinois (Jacobs, Williges, and Roscoe, 1973; Roscoe, Denney, and Johnson, 1971) support this finding. However, there is no evidence one way or the other to indicate that this improvement transfers to flight. The general experimental finding that relatively difficult training tasks yield higher transfer than easier ones suggests that transfer might be reduced as a consequence of adding motion cues that make the simulated flight task easier.
>
> The evident reason that large sums are spent for simulator motion systems, with no evidence of their training value, is their high face validity. A high-fidelity motion system is a delight to any pilot; the illusion of flight is extermely realistic. The decision to include a complex motion system is invariably determined by the enthusiasm of pilots, particularly one in high places.

The visual systems situation is similar in some respects. Available options range from the relatively simple and inexpensive (Payne et al., 1954) to the extremely complex and costly (Smith, 1972). The difference is that none of the visual systems developed to date are entirely satisfactory. Some systems severely limit the field of view; some severely limit the maneuvering area and/or altitude range; some have unacceptably poor resolution and/or image distortion; some lack color and/or texture and/or daylight representation; some tend to be unreliable; some require huge amounts of energy; some present serious radiation hazards, particularly for instructors and maintenance personnel; and all tend to require excessive maintenance.

A visual system suitable for teaching all of the perceptual-motor and decision-making skills required for NOE tactical helicopter operations does not exist. Nor is it likely that a cost-effective system which meets all NOE training requirements can be developed at the present time. The decreasing cost of high-speed digital computers and the recent advances in digitally-driven, solid-state displays may eventually provide a cost-effective solution. At the moment, however, the inadequacy of visual simulation is less important than a rational determination of the visual cues essential for meeting NOE training objectives.

TRAINING OBJECTIVES

Determination of static and dynamic visual cues, dynamic motion cues, auditory cues, and dynamic vehicle responses to be simulated should start with an analysis of training objectives associated with the appropriate mission--in this case, nap-of-the-earth helicopter operations. The training objectives for NOE (Gainer and Sullivan, 1976b) may be classified under the following set of behavioral categories useful in specifying associated simulator characteristics:

PROCEDURAL ACTIVITIES

Communications management
Navigation management
Fuel and powerplant management
Vehicle configuration management
Sensor management
Weapon management
Battle damage management

DECISION-MAKING ACTIVITIES

Navigation planning
Threat or hazard assessment
Target priority adjustment
Mission priority adjustment
Crew function adjustment

PERCEPTUAL-MOTOR ACTIVITIES

Geographic orientation
Vehicle control
Target, threat, or hazard detection and identification
Weapon delivery control
Communication

Each of the training objectives for nap-of-the-earth tactical helicopter operations can be classified under one or more of these behavioral categories. Consideration of previous simulation training reveals that, although simulators have proven highly effective in the teaching of procedural skills and only slightly less effective for teaching perceptual-motor skills (Flexman, et al., 1972), they have rarely been used to teach decision making skills. This is not surprising in view of the intangible nature of such skills, and the difficulty of defining and determining good decision-making performance. The ability to make good decisions is the distinguishing mark of the effective aircraft commander. The cultivation of these skills is an instructional objective calling for situational training that may be carried out safely only in a simulated tactical environment.

Further generalizations can be made concerning interrelations between training objectives and simulator characteristics before considering implications for the role of simulation in NOE training. The 1972 Flexman study concluded that:

> ...higher transfer occurs with procedural tasks than with psychomotor tasks because the former are less adversely affected by the imperfect simulation of such dynamic factors as physical motion, visual and kinesthetic cues, and control pressures.

> This is not to say that effective transfer of procedural tasks requires less fidelity of simulation than psychomotor tasks. To the contrary, the conclusion must be that procedural fidelity is more critical than dynamic fidelity is simulator design. Lack of procedural fidelity results in the transfer of incorrect responses, thereby yielding negative transfer to the performance of correct procedures in flight.

Another consideration when determining training objectives for simulators is the relative rate of forgetting for various skill categories. In general, once perceptual-motor skills are learned, they are not quickly forgotten. Former pilots often land an airplane safely and smoothly after as long as 20 years out of the cockpit. Procedural skills, on the other hand, are quickly forgotten. A World War II pilot who can still land his combat airplane safely is unlikely to be able to start its engines. The generalization that procedural skills are forgotten more rapidly than perceptual-motor skills was confirmed experimentally by Mengelkoch, Adams, and Gainer (1958). The fact that infrequently-used procedural skills can be retained (and partially forgotten ones quickly restored) in a simulator argues for maintaining high procedural fidelity.

FIDELITY REQUIREMENTS

Flight training devices should help train pilots to fly airplanes. Although cockpit motion adds realism, thereby improving pilot performance in the simulator (Fedderson, 1961; Guercio and Wall, 1972; Ince, Williges, and Roscoe, 1975; Jacobs, et al., 1973; Roscoe, et al., 1971), no evidence yet exists that cockpit motion in a ground-based trainer improves pilot performance in an aircraft. The issue is unresolved. No transfer of training experiment has been conducted in which either the degree or fidelity of cockpit motion was the experimental variable.

It has been demonstrated that the outcome of behavioral engineering in simulators (investigating the order of merit of flight displays) can produce quite different conclusions from experiments conducted in flight, depending upon the presence or absence and type of simulator cockpit motion (Bauerschmidt and Roscoe, 1960; Ince, et al., 1973; Johnson and Roscoe, 1972; Matheny, et al., 1965; Nygaard and Roscoe, 1953; Roscoe, et al., 1971; Roscoe, Hopkins, and McCurley, 1955; Roscoe and Williges, 1973; Roscoe, Wilson and Deming, 1954; Weisz, Elkind, Pierstorff, and Sprague, 1960; Williges and Roscoe, 1973). It would be surprising if the degree and fidelity of cockpit motion did not influence training effectiveness; however, the nature of that influence, positive or negative, has not been clearly established.

Koonce (1974) found a statistically reliable indication that the refreshment of instrument flying skills, as measured in flight, is enhanced by the absence of cockpit motion during practice in a simulator immediately before flight. As a result of this finding, the first direct experimental investigation of this question has been undertaken at the University of Illinois (experiment by R. S. Jacobs and S. N. Roscoe). Transfer of training from a modified Link general aviation trainer to a light general aircraft, using a flight syllabus that samples procedural, decision-making, and perceptual-motor activities, is being measured for three different cockpit motion conditions. These include no motion (as a reference condition), normal washout motion, and a hybrid washout motion condition in which the direction of cockpit motion is randomly reversed 50 percent of the time, thereby compounding the conflict between visual and vestibular cues. In the transfer control condition, all training is given in flight.

Similarly, few data exist to help determine the optimum fidelity of extra-cockpit visual simulation for contact flight training. Perhaps the light airplane will continue to be the most cost-effective and energy-effective contact flight trainer, fixed-wing or rotary-wing, for years to come. Certainly, flight trainers designed to teach the basic contact flight skills involved in takeoff and landing should be relatively inexpensive because comparatively few flight hours in relatively low-cost aircraft need to be saved. However, a more expensive simulator is justified to save pre-solo and transitional flight hours, because these training phases are disproportionately dangerous and costly in terms of damaged aircraft.

Analysis of the training objectives for nap-of-the-earth flight and tactical weapon delivery indicates that the most difficult problem areas are associated with cognitive skills rather than motor skills. Not only are procedural activities primarily cognitive, but they tend to be mission-specific, or at least specific to the particular aircraft and operational environment; conversely, perceptual-motor flying skills tend to generalize to a range of aircraft and missions. Although nap-of-the-earth flight control requires a fine touch and sustained attention, it involves the same flying skills as takeoff and landing, hovering, and formation flying. In contrast, the perceptual and decision-making skills required to maintain geographic orientation during NOE flight are not called for in any other type of flight operation (McGrath, 1972).

Avoiding the use of helicopters to teach NOE flight might warrant the development of fairly complex synthetic training devices. The difficulty of teaching NOE flight is strongly associated with geographic orientation and tactical decision making, and these training requirements demand high fidelity of the visual environment. Because a synthetic system that satisfies all requirements for simulating the visual field is likely to be inordinately expensive, there is ample reason to question the practicality of flight simulators for teaching many of the skills unique to NOE operations. Light aircraft, part-task trainers, motion pictures and video tapes, cinematic simulators, and digital teaching machines are among the available alternatives.

One issue in synthetic flight trainer technology remains undisputed: The importance of procedural fidelity. Although it is logistically difficult to keep changes in simulator cockpits consistent with changes in operational aircraft cockpits, the consequences of not doing so are tutorially disastrous.

INNOVATIONS IN PILOT TRAINING

Meeting the Army's training objectives for nap-of-the-earth flight operations may be facilitated by the imaginative application of recent innovations in pilot training. Among innovations that should be considered are automatically adaptive training, computer-assisted instruction, adaptive measurement of residual attention, automatic performance measurement, cinematic simulation, and the use of interactive computer-control-display devices.

AUTOMATICALLY ADAPTIVE TRAINING

Although all individualized training is, in a sense, adapted to the individual student's progress, the term adaptive training refers to the automatic adjustment of the training task as a function of the student's automatically measured performance (Kelley, 1969a; 1969b; McGrath and Harris, 1971). The task variable that is adjusted, called the adaptive variable, may be the difficulty, complexity, or newness of the training task (Crooks and Roscoe, 1973; McGrath and Harris, 1971; Williges, et al., 1973). For example, the difficulty of nap-of-the-earth flight control might be adjusted by automatically increasing the ruggedness of the terrain as the student's performance improves; the complexity of his task might be adjusted by increasing the frequency of concurrent radio communications; and new task elements might be introduced by simulating enemy ground fire when the student achieves specified proficiency levels in flight control and communication procedures.

The principal difference between automatically adaptive training and the adjustment of training tasks by a flight instructor is that automation requires that all decision rules for adjusting the task be predetermined. This requires a formal structuring of the complete training process in advance.

Although adaptive training has been studied in the laboratory for more than a decade[3] its first attempted application to the routine training of pilots was incorporated in the Army's SFTS helicopter simulator (Caro, 1969, 1973; Clausen, Curtin, and Egler, 1968; Jameson, Walsh, Flexman, and Cohen, 1968; McGrath and Harris, 1971; Walsh and Flexman, 1970; Young and Hall, 1968). Because of the lack of prior systematic study in the selection of adaptive variables and the stabilization of adaptive logic, the initial implementations have not yet been used in routine training. The only two adaptive variables which have been manipulated were the severity of air turbulence while flying an ILS approach (increasing as the student's control improves) and the stability of cyclic control dynamics during hover (decreasing as the student learns to control an initially stable vehicle).

Subsequent research at the University of Illinois has led toward a better understanding of the dynamics of intraserial effects during adaptive training in manual control (Crooks and Roscoe, 1973). Had this research been done before the SFTS was designed, it could have predicted that adjusting the control dynamics of the simulated helicopter from stable to unstable might interfere with, rather than facilitate, learning. By changing control dynamics as learning occurs, different responses to the same display indications are required from one point in training to the next. Although the training task progresses from easy to difficult, as desired, response patterns just learned must be replaced as they gradually become inappropriate. Students who practiced with unstable control dynamics from the beginning attained proficiency more quickly than most of the adaptively trained groups.

The fact that the automatic adjustment of control dynamics was found to be maladaptive (in this one experiment at least) should not discourage the further use of automatic adaptation of task difficulty, complexity, or newness. It merely indicates that care must be used to select adaptive variables that do not produce intraserial habit interference, and to tune the adaptive logic to the dynamics of human learning. Although a clearly effective implementation of automatically adaptive flight training has yet to be established, the principles governing its optimization are being studied at the University of Illinois (Wulfeck, Prosin, and Burger, 1973) and the Naval Missile Center, Point Mugu, California (Ehrhardt, Cavallero, and Kennedy, 1973). The basic idea is good.

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[3] See, for example, Birmingham, 1959; Birmingham, Chernikoff, and Ziegler, 1962; Chernikoff, 1962; Crooks and Roscoe, 1973; Damos, 1972; Hudson, 1962, 1964; Kelley, 1965, 1966, 1967; Kelley and Prosin, 1968; Kelley and Wargo, 1967; Lowes, Ellis, Norman, and Matheny, 1968; Matheny and Norman, 1968; Mirabella and Lamb, 1966; Pask and Lewis, 1962; Wood, 1969.

COMPUTER-ASSISTED INSTRUCTION

Automatically adaptive flight training is one form of computer-managed instruction; programmed cognitive training, which may or may not be adaptive, is another. However, the term computer-assisted instruction (CAI) refers to programmed learning in which an automatically branching logic allows each student to progress at his own rate (Atkinson and Wilson, 1969; Bitzer and Johnson, 1971; Crowder, 1959; Glaser, 1965; Holding, 1965; Lewis and Pask, 1965; Lumsdaine and Glaser, 1960; Pask, 1960; Skinner, 1958; Trollip and Roscoe 1972). Programmed learning is not necessarily cognitive in nature; some recent CAI programs teach psychomotor skills.

CAI is being applied to an established flight curriculum at the Institute of Aviation of the University of Illinois (Trollip and Roscoe, 1972). Initially, training in VOR navigation procedures is being done with the PLATO system, which eventually will have terminals throughout the nation and in some foreign countries. PLATO is the acronym for Programmed Logic for Automatic Teaching Operations (Bitzer and Johnson, 1971). PLATO IV, the operational version of the system, is now in regular use; it appears to be the only system currently applied to aviation training.

PLATO interacts with each student by presenting information and reacting to student responses. The instructor, or author, establishes the rules for every possible situation. An ingenious and thorough instructor can construct a set of rules with a flexibility approaching that possible for a human tutor--and rules are established in advance rather than spontaneously. In contrast to a conventional ground school classroom (in which an instructor manages many students simultaneously and seldom gives special attention to an individual student), PLATO appears to give each student undivided attention because it normally responds to each student's input in a fraction of a second. In this manner, each student receives rapid feedback of results, and new information or questions.

The display capabilities of PLATO allow instructors to present, or students to call up, stored graphic materials (such as special characters, maps, photographic slides, and printed or audio messages), and to construct geometric figures or graphs activated by commands of either the instructor or the student. A graphic display, for example, might allow a student to specify a route for NOE flight on a topographic map. The computer could then, from stored elevation and vegetation contours, display the changes in masking as the helicopter moves along the route at a designated clearance altitude.

Adaptive branching, individual-progression logic, and related CAI techniques have already been applied in computer-managed pilot training systems, notably in Device 2-B-24, the Army's SFTS simulator at Fort Rucker, Alabama. When fully implemented, the SFTS computer will monitor and evaluate student performance on selected flight tasks; it may require the student to repeat the same task, advance to a new task, or return to a previously mastered task for refreshment. Upon request, the student may observe a demonstration of the required performance by the computer.

The rapidly increasing sophistication and decreasing cost of computer-generated graphic display systems show promise of near-term application to training in real-time NOE tactical decision-making.

Although CAI systems such as PLATO IV are capable of certain types of perceptual-motor tasks simulation, their primary application to NOE flight training, testing, and currency maintenance appears to be cognitive. These applications might extend to the types of decision-making skills called for in different tactical situations, some of which require estimation of conditional probabilities and risks associated with alternative courses of action in the face of uncertain enemy force deployment. Three-dimensional navigational and ballistic problem solutions are typically required in the NOE tactics.

Considerable ingenuity will be required to produce training exercises useful for developing decision-making skills and communicating knowledge required for NOE operations, but the potential clearly exists. The Army Infantry School's current programmed map reading course might offer a starting point for the application of CAI technology to NOE training. Enrollment in the existing course would refresh map-reading skills and CAI student procedures for pilots entering NOE training. With the application of a suitable computing and graphic display system, course scenarios and software programs could be developed in NOE map interpretation for geographic orientation, terrain and cover analysis, route selection, and evasive maneuver anticipation.

The development of any CAI course should not be undertaken without full appreciation of the tutorial ingenuity, attention to detail, mastery of subject matter, and amount of effort required. Often individuals who have developed or closely observed the development of successful CAI programs (and who are generally enthusiastic advocates of CAI application) tend to minimize the personal investment required for success. As a conservative comparison, the development of an effective CAI program is surely a more formidable exercise than writing, illustrating, and publishing a textbook covering the same material in corresponding detail.

ADAPTIVE MEASUREMENT OF RESIDUAL ATTENTION

NOE task requirements place unparalled demands on the pilot's attention. Skill in rapid time-sharing of attention among competing demands is a characteristic that distinguishes the effective NOE crew. The automatic measurement of a pilot's residual attention while performing demanding routine operations not only discriminates among pilots of differing native ability but also serves to assess the currency of skilled pilots and their readiness to cope with the occasional abnormal workload demands of combat or equipment malfunction (Roscoe and Kraus, 1973).

Investigators[4] studying a variety of aviation problems favor the use of cockpit side tasks for at least three related purposes: (1) to create elevated cockpit workload pressures, thereby flushing out inherent differences among primary task performances as a function of some display, control, or procedural variable; (2) to shift subtask priorities--for example, making the subtask being measured secondary rather than primary in the pilot's priority hierarchy; and (3) to measure the pilot's residual attention as an inferential index of the workload demands of his higher priority subtasks.

The automatic measurement of residual pilot attention has reliable variations of individual differences among pilots, pilot currency, and the display, control, or procedural variables being studied. This supports the idea that residual attention capacity might be a basis for selecting student pilots, and might be used as a test of currency or combat readiness for experienced pilots.

To date, the use of side tasks for the measurement of residual attention has been applied only in the experimental study of flight displays, controls, and procedures, and in the prediction of success in pilot training. However, these experiments show that the technique can produce a powerful learning effect in the important areas of attention-sharing and decision-making. Furthermore, because pilots decrease slightly in flying skill over long periods of inactivity but their procedural efficiency drops quickly and seriously (particularly in flight situations requiring attention-sharing and quick-decision responses), the automatic measurement of residual attention can provide a quick check on an experienced pilot's procedural currency as well as on a student's initial attainment of proficiency.

The introduction of an attention-demanding side task while a student pilot is attempting to fly an NOE mission (in either a helicopter or a flight simulator) can lead successively to annoyance, frustration, hostility, and panic. Nevertheless, pilots learn to divide their attention to cope with multiple task demands, and the substantial transfer of such learning to operational situations involving cockpit work overloads can be achieved with complete safety to student and instructor. Although independent, attention-demanding side tasks may inhibit the learning of primary NOE flight tasks initially, the eventual capacity to handle primary tasks while coping with distractions strengthens the pilot's ability.

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[4] See: Damos, 1972; Damos and Roscoe, 1970; Ekstrom, 1962; Hamilton, 1969; Hartman and McKenzie, 1961; Lazarus, Deese, and Osler, 1952; Kraus and Roscoe, 1972; Lindsay, Taylor, and Forbes, 1968; Pope, 1962; Siebel, Christ, and Teichner, 1965; Slocum, Williges, and Roscoe, 1971, Smith, 1969; Soliday and Schohan, 1965.

AUTOMATIC PERFORMANCE MEASUREMENT

A great deal has been written about automated measurement of pilot performance and its potential for providing a diagnostic record of the student pilot's progress in flight training (Baum, et al., 1973; McGrath and Harris, 1971; Knoop, 1966, 1967, 1968). Nevertheless, the problems and methods of measuring pilot performance, either automatically or manually, are not well understood. An initial difficulty is associated with the misconception that performance measurement is basically an instrumentation problem, and that no problem would exist if suitable instrumentation were available in every training aircraft and simulator. Although some instrumentation is inevitably required, this is a trivial aspect of the problem. The important aspects of pilot performance assessment fall into two categories: defining the indices of desired performance, and sampling the indices of actual performance.

The task of flying a helicopter--or operating any other vehicle--involves making a series of discriminations and manipulations. Discriminations must identify the indices of desired performance, or subgoals, which must be met to achieve the overall goal of the mission. By manipulating controls, the pilot tries to match the indices of actual system performance to the identified indices of desired performance. How closely he does so is the objective measure of the quality of his performance.

Thus, measurement of pilot performance must deal with indices of desired and actual performance--the pilot's ability to discriminate the former and to manipulate the latter. Historically, flight performance assessment has focused on a pilot's ability to execute specified maneuvers in which the indices of desired performance are given, but even here the lack of standardization has caused uncertainty. Different instructors vary widely in their own performances of the same maneuvers, and different check pilots base their scoring on widely differing indices of desired performance. Consequently, the first problem in assessing NOE flight performance is to define flight tasks that require the pilot to discriminate indices of desired performance correctly. The performance measurement system must know the correct indices of desired performance.

The establishment of desired performance indices for NOE flight must be done if automatic performance measurement is to have any validity. Furthermore, desired performance indices must be defined for procedural and decision-making flight activities, as well as for perceptual-motor activities, and all must be based on the specified training objectives.

Once desired performance indices are identified, automatic measurement requires only that instruments sample the corresponding indices of actual performance economically and meaningfully. A major problem with typical instrumentation systems is that they produce continuous records of too many dependent variables for either the instructor or the student to digest and comprehend quickly in the training environment. The solution is to determine which few variables correlate sufficiently with the composite of all relevant performance measures. Only these need be monitored. Conceivably, a single performance variable could correlate so highly with the composite of many variables that it alone would be a sufficient basis for scoring the entire performance (Roscoe, 1948; Roscoe, Hasler, and Dougherty, 1966).

Although it is seldom possible to assess the performance of a complex task by making a single observation, it is usually possible to do so by making a few observations at judiciously selected points. The keys to nap-of-the-earth flight performance measurement will be found in the construction of a testing program that adequately samples decision-making, procedural, and perceptual-motor skills common to a range of tactical missions, explicitly defining the indices of desired performance (in quantitative terms where possible) and comparing indices of actual to desired performance at the fewest critical points that will yield reliable scores. Points critical for performance measurement need not be critical to the success of the mission, or even to the task being performed. They are critical only in the sense that performance at these points correlates highly with overall performance of the task or mission; no direct cause and effect relationship need be inferred.

When synthetic flight training devices are used, automatic performance measurement is essential--but not for the reasons usually given. There is a widespread misconception that performance measurement has to be automatic to be objective, reliable, and valid, none of which is true. Objectivity has to do with whether what is being measured can be observed publicly, as opposed to subjective measurement which, by definition, is private. For two or more people to observe the same performance and agree on its quality or score, the indices of desired performance must be explicit. Flight instructors' ratings of student performances are subjective to the extent that different instructors have their own ideas about what constitutes correct or desired performance. Recording aids objectivity by making a student's performance more nearly public. Two or more observers, reviewing the records without distraction or personal hazard, are more likely to arrive at the same correct judgment about student compliance to the explicit indices of desired performance. Automating the judgment between actual and desired performance does not make the judgment objective.

Automatic measurement does not necessarily greatly increase reliability over that of two or more qualified observers (Dannekskiold, 1955; Ericksen, 1952; Gordon, 1949; Koonce, 1974; Povenmire, Alvares and Damos, 1970; Selzer, Hulin, Alvares, Swartzendruber, and Roscoe, 1972; Smith, Flexman, and Houston, 1952), nor is it related to the validity of performance measurement. Nevertheless, automatic performance measurement is essential to any pilot training and testing program that incorporates adaptive training techniques, computer-assisted instruction, or cross-adaptive side tasks. In all such training innovations, the task (whether decision-making, procedural, or perceptual-motor) is adjusted in response to the pilot's immediately preceding performance. In practice, both the scoring and the adjusting have to be done automatically rather than by the instructor, to assure continuity of operation, and, if in the air, safety of flight. In many situations, the instructor cannot simultaneously serve as safety pilot and observe critical dependent variables at precisely the critical times.

CINEMATIC SIMULATION

As distinguished from conventional training films and videotaped instructional materials, cinematic simulation refers specifically to the open-loop film presentation of dynamic visual scenes. Used most prominently in automobile driver training, cinematic simulation with high-resolution wide-angle color films may provide the only available cost-effective means for teaching helicopter pilots the perceptual, procedural, and decision-making skills of geographic orientation in NOE flight. A high-fidelity, closed-loop visual simulation that would present NOE flight up and down canyons, among trees and buildings, or over and under bridges and power lines is not yet possible.

The principal limitations of cinematic flight simulation methods are resolution, field of view, and predetermined flight path. The image resolution that can be attained with modern films and projection systems is "limited" only in the sense that it is less than the resolving power of the human eye directly observing the field of interest. Any other method of simulating the visual field (such as TV/terrain-model techniques) produces an image of much poorer resolution. Assuming that the cinematic simulator reconstructs the geometry of the visual field so that objects in the projected image appear at valid angles from the observer, the best resolution of the image would be about five minutes of arc. This is not sufficient resolution for NOE target acquisition task training but is adequate for geographic orientation and map interpretation training.

Cinematic simulators are limited in field of view only by economics. A full 360-degree field of view can readily be simulated, but if maximum image resolution is to be retained and image distortion is to be avoided, a multiple projector system is needed. The screen must be a section of a sphere and only a few observers (theoretically only one) can be presented a valid simulation at any given time. For practical classroom presentations of filmed materials, the maximum distortion-free field of view on a flat screen is approximately 90 degrees.

The main limitation of cinematic simulators is that they present a predetermined flight path; the observer must go where the photography aircraft went. Although cinematic simulators can provide closed-loop control of pitch, roll, yaw, and speed, the three translational degrees of freedom are fixed by the film. Cinematic methods do not permit students literally to navigate. Nevertheless, a large number of training objectives can be achieved. Geographic orientation at NOE altitudes involves detecting and identifying various types of navigational checkpoints, judging distances, seeking mask, interpreting terrain forms, relating sighted features to those portrayed on the map, and making navigational decisions. Training exercises designed to impart such skills and knowledge have used open-loop cinematic materials and part-task training methods and have successfully trained Navy pilots in high-speed, low-altitude navigation (Borden, 1968). The application of cinematic methods to NOE pilot training is at least equally promising.

INTERACTIVE COMPUTER-CONTROL-DISPLAY DEVICES

Recent engineering developments may make it possible to produce training systems of unprecedented capability and flexibility at much less cost than contemporary systems. Not only are the unit costs of integrated micro-electronic circuits falling, but promising new computational techniques (DeLugish, 1970; Volder, 1959; Walther, 1971) are being applied to flight training simulator development. Although the developments are still proprietary, their potential applications are great.

Display technology is also advancing rapidly. Plasma panel displays, invented and developed during the past decade (Hoehn and Martel, 1971; Johnson, Bitzer and Slottow, 1971), are ideally suited to computer-assisted instruction because they can be driven directly by a digital computer, and because their inherent memory and selective erasure eliminate the high-speed refreshing requirement that makes CRT systems expensive. Because plasma panels are translucent, they can also serve as optical projection screens. Although they are still relatively expensive, their inherently simple construction promises eventual low cost, and they consume little energy.

For certain applications, plasma panels have several disadvantages--including relatively low brightness and writing speed. Also, they still offer only monochromatic renditions. However, very recent developments in liquid crystal display technology appear to have solved the first two problems, and may eventually offer excellent and economical color rendition. Because liquid crystal displays are reflective, the brighter the ambient illumination, the brighter the display. Their principle of operation involves the local modulation of reflectivity; this is done digitally at television writing speeds. Liquid crystal displays, like plasma displays, are constructed in flat panels, are inherently simple, and are potentially inexpensive. They have great promise for application to simulator visual systems, as well as to aircraft cockpit displays for which high ambient sunlight has always presented a serious problem. The most advanced liquid crystal displays are currently proprietary to their developers.

Both plasma panel and liquid crystal displays lend themselves to interactive computer-control-display applications when used in conjunction with transparent touch-panel overlays, light pencils, or manually controlled cursors. Used in this manner, they provide highly flexible two-way communication between the computer and the student pilot or instructor, and the ready implementation (through software) of cockpit side tasks, performance feedback, and changes in adaptive logic. All of these may be programmed and/or selected from the cockpit.

CONCLUSIONS

Simulated flight training devices have demonstrated their utility in general helicopter pilot training, but they are limited in their applications to NOE flight training by the present lack of a good simulation of the extra-cockpit visual field. The most promising areas of application are in teaching the procedural and decision-making skills required for NOE operations. Synthetic flight trainers are well suited to training pilots in the detection and diagnosis of, and response to, contingency and emergency events that occur when operating at NOE altitudes; they should be employed for this purpose at least. They can also be adapted to tactical decision-making training, provided that a meaningful situational context can be set up for each problem. The use of simulated flight trainers to teach the perceptual/motor skills required in NOE flight will probably have to await the development of high-fidelity methods of simulating the visual field. In the meantime, part-task training, using cinematic methods combined with air training, appears to be the most promising cost-effective method of developing visual perception skills.

Automatic adaptive training methods cannot be recommended at this time, but they show promise for teaching some of the psychomotor skills required in NOE aircraft handling. In particular, precision hover performance may be a candidate for adaptive training procedures.

Computer-assisted instruction can be applied to many aspects of NOE training. Almost any part of the curriculum currently being taught by lectures is a candidate for CAI applications. A central terminal with peripherals in the operational units could effectively aid advance unit training by providing better standardization of instruction, plus the flexibility and "move-at-your-own pace" versatility that unit-level training requires. At the entry level, CAI can provide some of the same advantages and particularly could teach student pilots the indices of desired performance; this, in turn, would promote more effective flight training. The task analysis data produced by the present research (Gainer and Sullivan, 1976a, 1976b) could be used in developing computer programs of performance indices.

The measurement of residual attention could be a useful technique for assessing NOE pilot performance, and might also be applied to stress training. Automatic performance measurement might also be applied to aircrew assessment, but its practical utility will depend on identifying pivotal measures that correlate highly with total performance.

The use of interactive computer-display-control devices does not appear to have immediate applications to NOE training, except as an extension of CAI techniques. However, this developing technology shows promise for future applications, particularly in the area of NOE tactical decision-making.

REFERENCES

Atkinson, R. C., & Wilson, H. A. Computer-assisted instruction. In R. C. Atkinson and H. A. Wilson (Eds.) *Computer-assisted instruction.* New York: Academic Press, 1969.

Bauerschmidt, D. K., & Roscoe, S. N. A comparative evaluation of a pursuit moving-airplane steering display. *IRE Transactions on Human Factors in Electronics*, 1960, *HFE-1*(2), 55-61.

Baum, D. R., Smith, J. F., & Goebel, R. A. *Selection and analysis of UPT maneuvers for automated proficiency measurement development.* Brooks Air Force Base, TX: Air Force Human Resources Laboratory (AFSC), Technical Report AFHRL-TR-72-62, July 1973.

Bell, F. E., III. *Advanced simulation in undergraduate pilot training (ASUPT). technical fact sheet.* Brooks Air Force Base, TX: Air Force Human Resources Laboratory (AFSC), Technical Note AFHRL/FT TN73-01, May 1974.

Birmingham, H. P. The instantaneous measurement of human bandwidth. Naval Research Laboratory, Washington, DC. Paper presented at the 8th Annual Conference on Manual Control. Dunlap and Associates, Inc., Stamford, CT, May 1959.

Birmingham, H. P., Chernikoff, R., & Ziegler, P. N. The design and use of "equalization" teaching machines. Naval Research Laboratory, Washington, DC. Paper presented at the IRE International Congress on Human Factors in Electronics, Long Beach, CA, May 1962.

Bitzer, D. L., & Johnson, R. L. PLATO--a computer-based system used in the engineering of education. *IEEE Proceedings (Special Issue on Engineering Education)*, 1971, *59*, 960-968.

Borden, G. J. *Training pilots in the use of aeronautical charts: a conference report.* Goleta, CA: Human Factors Research, Inc., for JANAIR, NR 213-028, January 1968.

Caro, P. W., Jr. Adaptive training--an application to flight simulation. *Human Factors*, 1969, *11*, 569-575.

Caro, P. W., Jr. *Transfer of instrument training and the synthetic flight training system.* Alexandria, VA: Human Resources Research Organization, Professional Paper 7-72, May 1972.

Caro, P. W., Jr. Aircraft simulators and pilot training. *Human Factors*, 1973, *15*, 503-510.

Chernikoff, R. Human equalization: concept, machine, and measurement. In *Complex vehicular controls: proceedings of Office of Naval Research symposium, Farnborough, England.* Long Beach, CA: Douglas Aircraft Co., Inc., May 1962.

Clausen, J. T., Curtin, J. G., & Egler, J. F. *Concept formulation report, synthetic flight training system Device 2B24.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN-68-C-0108-1, July 1968. (AD 673 982)

Crooks, W. H., & Roscoe, S. N. Varied and fixed error limits in automated adaptive skill training. In M. P. Rane, Jr. and T. M. Malone (Eds.) *Proceedings of the seventeenth annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors Society, October 1973.

Crowder, N. A. Automatic tutoring by means of intrinsic programming. In E. Galanter (Ed.) *Automatic teaching.* New York: John Wiley, 1959.

Damos, D. L. *Cross-adaptive measurement of residual attention to predict pilot performance.* Savoy, IL: University of Illinois at Urbana-Champaign, Institute of Aviation, Aviation Research Laboratory, Technical Report ARL-72-25/AFOSR-72-12, October 1972.

Damos, D L., & Roscoe, S. N. *Cross-adaptive measurement of residual attention in pilots.* Savoy, IL: University of Illinois at Urbana-Champaign, Institite of Aviation, Aviation Research Laboratory, Technical Report ARL-70-9/AFOSR-70-2, October 1970.

Danneskiold, R. D. *Objective scoring procedure for operational flight trainer performance.* Port Washington, NY: Office of Naval Research, Special Devices Center, Technical Report SPECDEVCEN-TR-999-2-4, February 1955. (AD 149 547)

DeLugish, B. G. *A class of algorithms for automatic evaluation of certain elementary functions in a binary computer.* Urbana, IL: University of Illinois at Urbana-Champaign, Department of Computer Sciences, Report 399, June 1970.

Ehrhardt, L. E., Cavallero, F. R., & Kennedy, R. S. *Effect of a prediction display on carrier landing performance--Part 2: laboratory mechanization.* Pt. Mugu, CA: Naval Missile Center, Laboratory Department, Final Report, Project Order PO-2-0151, NR 196-106A, June 1973.

Ekstrom, P. Analysis of pilot workloads in flight control systems with different degrees of automation. Paper presented at the Institute of Radio Engineers International Congress on Human Factors in Electronics, Long Beach, CA, May 1962.

Ericksen, S. C. *A review of the literature on methods of measuring pilot proficiency.* Lackland Air Force Base, TX: Human Resources Research Center, Research Bulletin 52-25, 1952.

Feddersen, W. E. The effect of simulator motion upon system and operator performance. Paper presented at the Seventh Annual Army Human Factors Engineering Conference, Ann Arbor, MI, October 1961.

Flexman, R. E., Matheny, W. G., & Brown, E. L. Evaluation of the School Link and special methods of instruction in a ten-hour private pilot flight-training program. *University of Illinois Bulletin*, 1950, *47*(80), Aeronautics Bulletin 8.

Flexman, R. E., Roscoe, S. N., Williams, A. C., Jr., & Williges, B. H. Studies in pilot training: the anatomy of transfer. *Aviation Research Monographs*, 1972, *2*(1).

Flexman, R. E., Townsend, J. C., & Ornstein, G. N. *Evaluation of a contact flight simulator when used in an Air Force primary pilot training program: Part 1: overall effectiveness.* Lackland Air Force Base, TX: Air Force Personnel and Training Research Center, Technical Report AFPTRC-TR-54-38, September 1954. (AD 53730)

Gainer, C. A. and Sullivan, D. J. *Aircrew requirements for nap-of-the-earth flight.* ARI Research Report 1190. 1976. (a)

Gainer, C. A. and Sullivan, D. J. *Aircrew task analysis and training objectives for nap-of-the-earth flight.* ARI Research Memorandum 76-2. 1976. (b)

Glaser, R. (Ed.). *Teaching machines and programmed instruction, II.* Washington, DC: National Education Association, 1965.

Gordon, T. A. *The development of a standard flight check for the airline transport rating based on the critical requirements of the airline pilot's job.* Washington, DC: Civil Aeronautics Administration, Division of Research, Report 85, 1949.

Guercio, J. G., & Wall, R. L. Congruent and spurious motion in the learning and performance of a compensatory tracking task. *Human Factors*, 1972, *14*, 259-269.

Hamilton, P. Selective attention in multi-source monitoring tasks. *Journal of Experimental Psychology*, 1969, *82*, 34-37.

Hartman, B. O., & McKenzie, R. E. *Systems operator proficiency: effects of speed stress on overload performance.* Brooks Air Force Base, TX: School of Aerospace Medicine, Report 61-40, June 1961.

Hoehn, J. H., & Martel, R. A. A 60-line per inch plasma display panel. *IEEE Transactions on Electron Devices*, 1971, *ED-18*(9), 659-663.

Holding, D. H. *Principles of training.* London: Pergamon Press, 1965.

Hudson, E. M. An adaptive tracking simulator. Otis Elevator Company, Brooklyn, NY. Paper presented at the IRE First International Congress on Human Factors in Electronics, Long Beach, CA, May 1962.

Hudson, E. M. *Adaptive training and nonverbal behavior.* Port Washington, NY: Naval Training Device Center, Technical Report 1395-1, July 1964.

Ince, F., Williges, R. C., & Roscoe, S. N. Simulator motion and the order of merit of flight attitude and steering guidance displays. In M. P. Rane, Jr. and T. M. Malone (Eds.) *Proceedings of the seventeenth annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors Society, October 1973.

Jacobs, R. S., Williges, R. C., & Roscoe, S. N. Simulator motion as a factor in flight-director display evaluation. *Human Factors*, 1973, *15*, 573-586.

Jameson, W. P., Walsh, J. M., Flexman, R. E., & Cohen, E. *Synthetic flight training system (SFTS): concept formulation report.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN-68-C-0106-1, April 1968.

Johnson, R. L., Bitzer, D. L., & Slottow, G. H. The device characteristics of the plasma display element. *IEEE Transactions on Electron Devices*, 1971, *ED-18*(9), 642-649.

Johnson, S. L., & Roscoe, S. N. What moves, the airplane or the world? *Human Factors*, 1972, *14*, 107-129.

Kelley, C. R. Testing the effects of extended space missions on piloting skill. In E. Burgess (Ed.) *AAS science and technology.* Vol. 5, P. Horowitz (Ed.) *Physiological and performance determinants of manned space system design.* Baltimore, MD: American Astronautical Society, 1965.

Kelley, C. R. Self-adjusting vehicle simulators. In C. R. Kelley (Ed.) *The predictor instrument: final report and summary of project activities during 1961.* Arlington, VA: Office of Naval Research Technical Report, Contract Nonr 2822(00), January 1962. Also in C. R. Kelley (Ed.) *Adaptive simulation.* Arlington, VA: Office of Naval Research Final Report, Contract Nonr 4986(00), August 1966. (AD 637 658)

Kelley, C. R. *Further research with adaptive tasks.* Arlington, VA: Office of Naval Research Final Report, Contract Nonr 4986(00), August 1967.

Kelley, C. R. Adaptive and automated research techniques from engineering psychology. *American Psychologist*, 1969, *24*, 293-297.(a)

Kelley, C. R. What is adaptive training? *Human Factors*, 1969, *11*, 547-556.(b)

Kelley, C. R., & Prosin, D. J. *Adaptive performance measurement.* Arlington, VA: Office of Naval Research Final Report, Contract Nonr 4986(00), August 1968. (AD 677 049)

Kelley, C. R., & Wargo, M. J. Cross-adaptive operator loading tasks. *Human Factors*, 1967, *9*, 395-404.

Knoop, P. A. *Programming techniques for the automatic monitoring of human performance.* Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, Technical Report AMRL-TR-66-16, April 1966.

Knoop, P. A. Automated aids for flight simulator instructors. *USAF Instructor's Journal*, 1967, *4*(4), 61-64.

Knoop, P. A. *Development and evaluation of a digital computer program for automatic human performance monitoring in flight simulator training.* Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratories, Technical Report AMRL-TR-67-97, August 1968.

Koonce, J. M. *Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency.* Savoy, IL: University of Illinois at Urbana-Champaign, Institute of Aviation, Aviation Research Laboratory, Technical Report ARL-74-5/AFOSR-74-3, April 1974.

Kraus, E. F., & Roscoe, S. N. Reorganization of airplane manual flight control dynamics. In W. B. Knowles, M. S. Sanders, and F. A. Muckler (Eds.) *Proceedings of the sixteenth annual meeting of the Human Factors Society.*

Lazarus, R. S., Deese, J. E., & Osler, S. F. The effects of psychological stress upon performance. *Psychological Bulletin*, 1952, *49*, 293-317.

Lewis, B. N., & Pask, G. The theory and practice of adaptive teaching systems. In R. Glaser (Ed.) *Teaching machines and programmed learning. Vol. II: data and directions.* Washington, DC: National Education Association, 1965.

Lindsay, P., Taylor, M., & Forbes, S. Attention and multidimension discrimination. *Perception and Psychophysics*, 1968, *4*, 113-117.

Lowes, A. L., Ellis, N. C., Norman, D. A., & Matheny, W. G. *Improving piloting skills in turbulent air using a self-adaptive technique for a digital operational flight trainer.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN 67-C-0034-2, August 1968. (AD 675 805)

Lumsdaine, A. A., & Glaser, R. (Eds.). *Teaching machines and programmed learning: a source book.* Washington, DC: National Education Association, 1960.

Matheny, W. G., Dougherty, D. J., & Willis, J. M. Relative motion of elements in instrument displays. *Aerospace Medicine*, 1963, *34*, 1041-1046.

Matheny, W. G., & Norman, D. A. *The effective time constant in tracking behavior.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN 67-C-0034-3, August 1968.

McGrath, J. J. *The use of wide-angle cinematic simulators in pilot training.* Santa Barbara, CA: Anacapa Sciences, Inc., Technical Report NAVTRADEVCEN 70-C-0306-4, June 1972.

McGrath, J. J., & Harris, D. H. Adaptive training. *Aviation Research Monographs*, 1971, *1*(2).

Mengelkoch, R. F., Adams, J. A., & Gainer, C. A. *The forgetting of instrument flying skills as a function of the level of initial proficiency.* Port Washington, NY: Office of Naval Research, Naval Training Device Center, Technical Report NAVTRADEVCEN 71-16-18, 1958.

Micheli, G. S. *Analysis of transfer of training, substitution, and fidelity of simulation of training equipment.* Orlando, FL: Naval Training Equipment Center, Training Analysis and Evaluation Group, TAEG Report 2, 1972.

Mirabella, A., & Lamb, J. C. Computer based adaptive training applied to symbolic displays. *Perceptual and Motor Skills*, 1966, *23*, 647-661.

Nygaard, J. C., & Roscoe, S. N. *Manual steering display studies: I. Display-control relationships and the configuration of the steering symbol.* Culver City, CA: Hughes Aircraft Company, Technical Memorandum 334, October 1953.

Ornstein, G. N., Nichols, I. A., & Flexman, R. E. *Evaluation of a contact flight simulator when used in an Air Force primary pilot training program. Part II. Effectiveness of training on component skills.* Lackland Air Force Base, TX: Air Force Personnel and Training Research Center, Technical Report AFPTRC-TR-54-110, December 1954. (AD 62373)

Pask, G. Adaptive teaching with adaptive machines. In A. A. Lumsdaine and R. Glaser (Eds.) *Teaching machines and programmed learning: a source book.* Washington, DC: National Education Association, 1960, 349-366.

Pask, G., & Lewis, B. N. An adaptive automation for teaching small groups. *Perceptual and Motor Skills*, 1962, *14*, 183-188.

Payne, T. A., Dougherty, D. J., Hasler, S. G., Skeen, J. R., Brown, E. L., & Williams, A. C., Jr. *Improving landing performance using a contact landing trainer.* Port Washington, NY: Office of Naval Research, Special Devices Center, Technical Report SPECDEVCEN 71-16-11, March 1954. (AD 121 200)

Pope, L. T. *Attention level and visual and auditory monitoring performance.* Wright-Patterson Air Force Base, OH: Behavioral Sciences Laboratory, Technical Documentary Report MRL-TDR-62-97, August 1962.

Povenmire, H. K., Alvares, K. M., & Damos, D. L. *Observer-observer flight check reliability.* Savoy, IL: University of Illinois at Urbana-Champaign, Institute of Aviation, Aviation Research Laboratory, Technical Report LF-70-2, October 1970.

Povenmire, H. K., & Roscoe, S. N. An evaluation of ground-based flight trainers in routine primary flight training. *Human Factors*, 1971, *13*, 109-116.

Povenmire, H. K., & Roscoe, S. N. The incremental transfer effectiveness of a ground-based general aviation trainer. *Human Factors*, 1973, *15*, 537-545.

Puig, J. A. *Motion in flight training.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN IH-177, October 1970.

Roscoe, S. N. The effects of eliminating binocular and peripheral monocular visual cues upon airplane pilot performance in landing. *Journal of Applied Psychology*, 1948, *32*, 649-662.

Roscoe, S. N., Denney, D. C., & Johnson, S. L. *The frequency-separated display principle: Phase II.* Savoy, IL: University of Illinois at Urbana-Champaign, Institute of Aviation, Aviation Research Laboratory, Annual Summary Report ARL-71-15/ONR-71-1, December 1971. (AD 735 915)

Roscoe, S. N., Hasler, S. G., & Dougherty, D. J. Flight by periscope: making takeoffs and landings; the influence of image magnification, practice, and various conditions of flight. *Human Factors*, 1966, *8*, 13-40.

Roscoe, S. N., Hopkins, C. O., & McCurley, E. A. *Manual steering display studies: III. The transition of interceptor pilots to the moving-airplane display in the F-86D aircraft.* Culver City, CA: Hughes Aircraft Company, Section 2.0 of Report 507-03-P, December 1955.

Roscoe, S. N., & Kraus, E. F. Pilotage error and residual attention: the evaluation of a performance control system in airborne area navigation. *Navigation*, 1973, *20*, 267-279.

Roscoe, S. N., & Williges, R. C. Motion relationships in aircraft attitude and steering guidance displays: a flight experiment. In M. P. Ranc, Jr. and T. M. Malone (Eds.) *Proceedings of the seventeenth annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors Society, October 1973.

Roscoe, S. N., Wilson, K. V., & Deming, H. D. *Manual steering display studies: II. T he transition if skilled interceptor pilots from the E-series display to the moving airplane display.* Culver City, CA: Hughes Aircraft Company, Technical Memorandum 331, November 1954.

Seibel, R., Christ, R. E., & Teichner, W. H. Short-term memory under workload stress. *Journal of Experimental Psychology*, 1965, *70*, 154-162.

Selzer, U., Hulin, C. L., Alvares, K. M., Swartzendruber, L. E., & Roscoe S. N. Predictive validity of ground-based flight checks. In W. B. Knowles, M. S. Sanders, and F. A. Muckler (Eds.) *Proceedings of the sixteenth annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors Society, October 1972.

Skinner, B. F. Teaching machines. *Science*, 1958, *128*, 969-977.

Slocum, G. K., Williges, B. H., & Roscoe, S. N. Meaningful shape coding for aircraft switch knobs. *Aviation Research Monographs*, 1971, *1*(3), 27-40.

Smith J. F. Applications of the advanced simulation in undergraduate pilot training (ASUPT) research facility to pilot training programs. In E. B. Tebbs (Ed.) *Third annual symposium: proceedings of psychology in the Air Force.* Colorado Springs, CO: USAF Academy, Department of Life Sciences, April 1972.

Smith, J. F., Flexman, R. E., & Houston, R. C. *Development of an objective method of recording flight performance.* Lackland Air Force Base, TX: Human Resources Research Office, Technical Report 52-15, December 1952.

Smith, M. Effect of varying channel capacity on stimulus detection and discrimination. *Journal of Experimental Psychology*, 1969, *82*, 520-526.

Smode, A. F., Hall, E. R., & Meyer, D. E. *An assessment of research relevant to pilot training.* Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, Technical Report AMRL-TR-66-196, November 1966. (AD 804 600)

Soliday, S. M., & Schohan, B. Task loading of pilots in simulated low-altitude high-speed flight. *Human Factors*, 1965, *7*, 45-53.

Trollip, S. R., & Roscoe, S. N. Computer-assisted instruction in pilot training and certification. In W. B. Knowles, M. S. Sanders, and F. A. Muckler (Eds.) *Proceedings of the sixteenth annual meeting of the Human Factors Society.* Santa Monica, CA: Human Factors Society, October 1972.

Valverde, H. H. *Flight simulators. A review of the research and development.* Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, Technical Report AMRL-TR-68-97, July 1968. (AD 855 582)

Valverde, H. H. A review of flight simulator transfer of training studies. *Human Factors*, 1973, *15*(6), 510-522.

Volder, J. E. The CORDIC trigonometric computing technique. *IEEE Transactions on Electronic Computers*, 1959, *EC-8*(5), 330-334.

Walsh, J. M., & Flexman, R. E. *Preliminary adaptive training design report for synthetic flight training system Device 2B24.* Orlando, FL: Naval Training Device Center, Technical Report 69-C-0200-15, April 1970.

Walther, J. S. A unified algorithm for elementary functions. *AFIPS Conference Proceedings*, 1971, *38*, 379-385.

Watson, W. W., Cooles, H. D., & Hotz, H. E. *Future undergraduate pilot training system study: Appendix XII. Candidate synthetic flight training requirements.* Wright-Patterson Air Force Base, OH: Aeronautical Systems Division, Air Force Systems Command, Final Report NOR 70-149, March 1971.

Weisz, A. Z., Elkind, J. I., Pierstorff, B. C., & Sprague, L. T. Evaluation of aircraft steering displays. *IRE Transactions on Human Factors in Electronics*, 1960, *HFE-1*(2), 55-61.

Williams, A. C., Jr., & Flexman, R. E. *An evaluation of the SNJ operational trainer as an aid in contact flight training.* Port Washington, NY: Office of Naval Research, Special Devices Center, Technical Report 71-16-5, July 1949.(a)

Williams, A. C., Jr., & Flexman, R. E. Evaluation of the School Link as an aid in primary flight instruction. *University of Illinois Bulletin*, 1949, *46*(71), (Aeronautics Bulletin 5).(b)

Williams, A. C., Jr., & Flexman, R. E. The efficiency of a synthetic flight training device as a function of its design characteristics. *American Psychologist*, 1949, *4*, 301.(c)

Williges, B. H., Roscoe, S. N., & Williges, R. C. Synthetic flight training revisited. *Human Factors*, 1973, *15*, 549-564.

Wood, M. E. Continuously adaptive versus discrete changes of task difficulty in the training of a complex perceptual-motor skill. *Proceedings of the 77th Annual Convention of the American Psychological Association*, 1969, *4*, 757-758.

Wulfeck, J. W., Prosin, D. J., & Burger, W. J. *Effect of a prediction display on carrier landing performance--Part 1: experimental evaluation.* Inglewood, CA: Dunlap and Associates, Inc. Final Report, Contract N00014-71-C-0252, NR 196-106, June 1973.

Young, F. E., & Hall, E. R. *Synthetic flight trainer system (2B24): concept formulation report.* Orlando, FL: Naval Training Device Center, Technical Report NAVTRADEVCEN 68-C-0107-1, July 1968.